

N70-71953
RE-ORDER NO. 66-94

NASA-CR-108008

This work was performed for the Jet Propulsion Laboratory,
California Institute of Technology, sponsored by the
National Aeronautics and Space Administration under
Contract NAS7-100.

TAPE RECORDER BELT STUDY
FINAL REPORT

on

Thermal Shrinkage of Polyester Base
Magnetic Tape

**CASE FILE
COPY**

By

Irving Karsh, Project Manager

Prepared For

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California

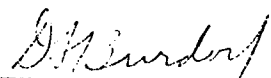
Contract No. 950899
January 1966

Warren Clement
Senior Research Engineer

James Hoffman
Cognizant Engineer




Irving Karsh


D. L. Burdorf, Vice-President

KINELOGIC CORPORATION

10-132

TABLE OF CONTENTSPage No.

SUMMARY AND CONCLUSIONS	1
PURPOSE AND INTRODUCTION	3
TEST EQUIPMENT AND METHOD	5
TEST CONDITIONS AND RESULTS	10
TABLE I, Test Conditions of Phase 1	10
TABLE II, Test Conditions of Phase 2	11
TABLE III, Test Conditions of Phase 3	11
TABLE IV, Test Conditions of Phase 4	13
TABLE V, Test Data	17
TABLE VI, Test Data Variability	20
FIGURE 1, Photo of Test Equipment	21
FIGURE 2a, Plot of Phase 1 at 100 psi	22
FIGURE 2b, Plot of Phase 1 at 500 psi	23
FIGURE 2c, Plot of Phase 1 at 1,000 psi	24
FIGURE 3, Plot of Phase 2	25
FIGURE 4, Plot of Phase 3	26
FIGURE 5, Plot of Response to Stress and Temperature	27
FIGURE 6, Plot of Response to Stress and Time of Exposure	28
FIGURE 7, Plot of Second Thermal Exposure at 100 psi	29
FIGURE 8, Plot of Second Thermal Exposure at 1,000 psi	30

SUMMARY and CONCLUSIONS

The dimensional changes of polyester based magnetic tape as a result of exposure to elevated temperature, while under stress, were measured for a range of temperatures and stresses which might be encountered in magnetic tape recorders. A second lot was exposed to two distinct cycles of exposure.

When the tape is subjected to elevated temperatures while under stress, irreversible dimensional changes occur. The net change seems to be a shrinkage if the stress is below 200 psi and becomes an elongation if the stress is above 200 psi. This change in length varies directly with the temperature, stress, and time of exposure. Since the normal tension in magnetic tape is on the order of 1,000 psi, it would appear that tape recorders which are exposed to elevated temperature will experience permanent elongations of the tape which are proportional to the temperature and the time of exposure. The rate at which the temperature was increased (heat up rate) was found to not influence the dimensional changes.

The series of tests with two cycles of exposure show that the response to the second exposure is not influenced by the previous exposure. The conclusions drawn from the first three phases are then directly applicable to any exposure regardless of the previous history. Where frequency

stability is important, compensating techniques will be required. A major aim of this program was to determine whether a thermal pre-treatment of the tape would minimize these dimensional changes and it must be concluded that none exists within the range of variables here tested.

PURPOSE AND INTRODUCTION

This study was designed to obtain information about the dimensional changes which occur in polyester based magnetic tape as a result of exposure to elevated temperature while being stressed and then to determine whether it is possible to minimize dimensional changes in service by a pre-conditioning treatment.

Magnetic recording tapes are used as data storage elements in various data acquisition systems. These systems are in turn being subjected to increasingly severe thermal environments. Unfortunately the base material, polyester film, shows both reversible and irreversible dimensional changes during and after exposure to elevated temperatures. E. I. duPont in its Bulletin M-2A indicated that the material will show an irreversible shrinkage of 0.3% after exposure to 80°C (176°F) for thirty minutes with no load, when measured at room temperature. In addition, the material also shows a reversible thermal expansion of 15 microns per inch per degree F. This indicates that significant dimensional changes can occur between the recording and the recovery of the data.

This dimensional change can cause errors in the recorded signal and also can cause difficulties in the control of the tape travel. It therefore follows that it would be very desirable to develop techniques which minimize dimensional changes. To this end the dimensional changes in magnetic tape subjected to various thermal treatments were measured and then the

response to a subsequent treatment was measured. The response to the subsequent treatment was then compared to the initial response to the same treatment to determine whether any beneficial change in response was obtained.

TEST EQUIPMENT AND METHODS

The apparatus which was used to load the tape and measure the dimensional changes is shown in Figure 1. The oven can be seen in the background. This oven was modified in two ways for this program. The expanded metal shelf was replaced with a 1/4 inch aluminum plate that had several ventilation holes in it. The rear wall of the oven was cut out and a double pane window was installed. The double pane window was employed to reduce heat losses and achieve a more nearly uniform temperature in the oven. The normal heatup rate is about 80° F/hour. Immediately in front of the oven is the sample holding fixture and the weight positioning fixture. These two fixtures are used together to position the sample and the weight so that the weight is parallel to the upper clamp and the tape sample is loaded with a uniform stress across its width. A bubble vial is mounted on the positioning fixture as a level reference. The lower clamp on the tape and the pan, which can be seen between the holding and positioning fixtures, are sized to provide a stress of 100 psi on the tape backing. Additional weights are provided to obtain stresses of 500 and 1,000 psi. The lowest stress (100 psi) was selected as being the lowest practical stress which would permit positive control of the tape during a thermal treatment cycle, if a suitable treatment were found. The highest stress (1,000 psi) was chosen as this is the stress resulting from the usual tape tension in tape recorders and also was safely below the yield point at the maximum temperature to be tested. The third stress used was intermediate in value.

The standard heatup rate, ($80^{\circ}\text{F}/\text{hour}$) which was used in all tests where this was not the variable, was selected because this was the normal heatup rate of the test oven. This is the average rate which is obtained by dividing the temperature rise by the time to first reach the test temperature. The other rates were selected to provide a significant change in magnitude while permitting any one test to be completed within an eight hour day. The standard time at temperature ($1\text{-}1/4$ hours) was selected to be longer than the time indicated by E. I. duPont, and also in several (now lost) references to the shrinkage of tape in high environment recorders. These sources indicated that the major portion of the shrinkage occurs during the first ten to fifteen minutes of exposure. On the other hand, some poorly controlled in-house tests, performed for another purpose, indicated that measurable amounts of shrinkage occurred at least for the first hour of exposure. This period was then selected as the shortest practical period. Longer periods were also tested with the longest period (6 hours) allowing a complete test run in an eight hour day.

The two sample clamps carry engraved lines which are used to measure the length of the sample. The distance between these engraved lines is measured with a cathetometer which is shown in the foreground of Figure 1. The cathetometer is a standard laboratory instrument for measuring linear displacement. This one measures vertical displacement. The cathetometer consists of short range telescope with precision level and crosshairs, which slides on a calibrated column. The carriage carries a vernier to

provide a reading of vertical position to 0.05 mm. The gauge length of the sample is about 260 mm so that a resolution of 0.004% of the gauge length is possible.

The oven was placed on a bench so that the door at the front of the oven and the window in the back were accessible. The oven was then leveled so that the shelf, in the area where the loading fixture would be placed, was level. The bubble vial on the positioning fixture was used for this purpose. The cathetometer was placed opposite the window in the oven in a position such that the interior of the oven could be viewed conveniently. The cathetometer was placed on a platform to raise the 100 cm long column to the operating level. Once in place the column was made plumb and the telescope axis set square to the column following the procedure given by the manufacturer. When the column is plumb and the telescope axis is square to the column, a horizontal plane is generated as the telescope is rotated about the column. This condition is obtained when the precision bubble vial does not indicate a shift with the telescope pointed in any direction.

The test setup procedure is started by placing the loading fixture in a convenient working space on a bench. The positioning fixture is placed in the bottom of the loading fixture. The loading fixture is leveled, using the bubble vial which is mounted on the positioning fixture and a leveling screw (which is not shown in Figure 1). The upper clamp is loosened and the lower clamp, loosely assembled, is set in the notch in the positioning fixture.

These notches hold the lower clamp parallel to and centered beneath the

upper clamp. A sample of tape 16 to 20 inches long is cut from the reel and threaded through the upper clamp and then drawn through the lower clamp. All the samples of magnetic tape used in this program were taken from one reel of 1 mil base tape. The side pieces of the positioning fixture and a notch above the upper clamp center the sample in the fixture. The tape is drawn back through the lower guide until it just barely protrudes through the lower guide, which is then tightened. The tape is then drawn back still further so that the bottom of the lower clamp clears the second notch. The tape above the upper clamp is then wiggled until the sample hangs freely between the side members of the positioning fixture. The upper clamp is then tightened. The sample is now positioned with the two clamps parallel to each other and with the sample under a uniform stress across its width. The assembly is next transferred to the oven and re-leveled. The positioning fixture is removed and the proper weights attached to the lower clamp. The loading fixture is then rotated so that the engraved lines can be viewed through the window by the telescope on the cathetometer. Since the shelf was leveled previously, the loading fixture remains leveled. The heights of the two clamps are then measured with the cathetometer. The oven is then closed and turned on with the thermostat preset for the test temperature. Successive sets of readings are then taken at fifteen minute intervals during the heatup period and are continued until the sample has been at the test temperature for 1-1/4 hours. In one series of tests the time at temperature was extended and in these tests the readings were taken at 30 minute intervals for the remainder of the test period.

Another series of tests was run with a series of different heatup rates. In these tests the heatup rate of the oven was decreased by reducing the supply voltage with a variable transformer. The test technician was given a data sheet which specified the test conditions (temperature, temperature rate, stress, and time at temperature) for each test. Space was provided on this sheet to record the time, temperature, and upper and lower reference readings. Additional columns were provided on this data sheet to provide space for the calculation of the length and change in length of the sample for each set of readings. The test technician did this calculation during the waiting periods.

For the tests where the sample was subjected to two treatments, the test technician was given two data sheets. The first sheet indicated both sets of conditions and the second sheet showed the condition of the second treatment only. For this series of tests the sample was put through the first treatment on one day, cooled to room temperature and kept overnight. The next day the sample was put through the second treatment.

TEST CONDITIONS AND RESULTS

The test conditions selected in this study were arrayed to investigate four environmental variables. These variables are: stress, temperature, rate of temperature rise, and time at temperature. In Phase I the first two variables were set up in a two dimensional pattern as shown below:

TABLE I
Phase I

Temperature	Stress, psi		
	100	500	1,000
150 F.	1	2	3
200 F.	4	5	6
250 F.	7, 28 to 31	8	9
300 F.	10	11	12

The heatup rate and the time at temperature were held constant, at 80^o F/hour and 1-1/4 hours, respectively, for the tests listed in Table I. Note that the numbers in the bodies of Tables I, II, III and IV are the test identification numbers and are the key to the tabulation of test data in Table V, Page 17.

Each of the last two variables were set up each in a two dimensional pattern with stress as the second variable. These last two patterns, representing Phases 2 and 3 respectively, each intersect the first pattern at the level of 250^o F. These patterns are shown below:

TABLE II
Phase 2

Temperature Rate	Stress, psi		
	100	500	1,000
Preheated Oven	25	26	27
80 degrees/hour	7, 28 to 31	8	9
50 degrees/hour	19	20	21
30 degrees/hour	22	23	24

TABLE III
Phase 3

Time at Temperature	Stress, psi		
	100	500	1,000
1-1/4 hours	7, 28 to 31	8	9
3 hours	13	14	15
6 hours	16, 32 to 35	17	18

The temperature and time at temperature were held constant, at 250^o F and 1-1/4 hours, respectively, except 3 hours for the run with the preheated oven for the tests listed in Table II. In Table III the temperature and heatup

rate were held constant at 250°F and $80^{\circ}\text{F}/\text{hour}$, respectively.

In addition to these three arrays of test points two of the sets of test conditions as indicated by the test numbers in Tables I, II and III, were tested an additional four times to establish the variability of the test data.

The above conditions establish the response of magnetic tape to thermal exposure under the range of conditions which might be encountered in tape recorder service in extreme environments. In Phase 4 an additional battery of tests was run with each sample subjected to two treatments.

In each case the first temperature was higher than or equal to the temperature of the second exposure. Two different stress levels were selected for this phase of the test program, the highest and lowest of the three stresses used earlier. Only three of the four possible combinations of two stress levels in two cycles were tested. The reasoning behind this ordering of test conditions is:

1. The net dimensional changes should be proportional to the temperature.
2. If the dimensional change is irreversible a lower temperature should not have any effect after a previous exposure.
3. A lower stress level should permit a more complete relief of residual stresses.
4. Exposures at two temperatures (regardless of stress level) at a given stress level should show the same pattern, if not degree, of response.
5. The tape will be exposed to the higher stress level in service.
6. The possibility of a thermal pretreatment at a high stress level was tested by using a lower stress level on the second exposure. The two stress levels used were the same as used in the previous tests to permit direct comparison.

The pattern of test conditions is shown below:

TABLE IV.
Phase 4

Temperature, F.	Stress, psi		
	100/100	1,000/100	100/1,000
250/150	36	37	38
250/200	39	40	41
250/250	42	43	44
300/250	45	46	47

The conditions of stress and temperature for the first treatment are given above the slash line and for the second treatment below the slash line in the above table. The heatup rate and the time at temperature were held constant at 80^o F/hour and 1-1/4 hours, respectively, in this test block.

In each of the first three phases of the test program, for initial response to thermal exposure under stress, the change in length was first reduced to a percentage change and then plotted. The changes in length observed in each test run and the test conditions are given in Table V. The three plots (Figures 2a, 2b, 2c, 3 and 4) which are discussed later, are of treatment temperature, heatup rate, and time at temperature as the independent variables in each case with the percentage change in length as the dependent variable.

Two sets of test conditions were selected for replication before the program was started. Both these sets had a stress level of 100 psi at 250^o F and

and 80° F/hour heatup rate, since it was anticipated that these might be the conditions which would be used in a pre-conditioning treatment if one were found suitable. The first of the two sets of replications was also at the intersection of the test patterns for the first three phases so that maximum use could be obtained from this set. The second set was done at an extended (6 hour) exposure since it was felt that it might require an extended period to assure complete treatment of an entire reel of tape. The response at 100 psi is somewhat erratic, as can be seen in Figures 2a and 4, and the variability under these conditions is probably greater than for the higher stress levels used in this test program. However, it was required that the complete schedule of testing be specified before the start of the test program and we felt constrained to carry the original schedule through. The mean value of the percentage change in length and the standard deviation for these two replicated runs, expressed as a fraction of the mean change and of the mean percentage change in length are given in Table VI. These values of the standard deviation can be used to estimate the reliability of the other data points.

The data plots for the first three phases of the test program (Figures 2a, 2b, 2c, 3 and 4) each have the stress as a parameter. The first and third phases each show a distinct trend with the independent variable; treatment temperature and time at temperature, respectively. The second phase, with heatup rate as the independent variable, shows that the dimensional changes are not affected by rate of heating. In all three phases the dimensional

change while cooling is a function of the temperature but not of the applied stress.

In the first phase it can be seen in Figures 2a, 2b and 2c that the tape shrinks, when stressed at 100 psi, at all the test temperatures while it stretches at the two other stress levels. Furthermore, the amount of stretch at 1,000 psi is greater than at 500 psi. In all three plots the dimensional change seems to be a straight line function of the temperature. If the slopes of these plots (percent change in length per degree F) are plotted against the stress (Figure 5) the percentage change in length can be seen to be a direct function of the applied stress. There is a strong suggestion that the percentage change per degree F increases as some power function of the applied stress.

Similarly in the third phase it can be seen in Figure 4 that a parallel response pattern is exhibited in respect to the time at temperature. The slopes, percent change in length per hour of exposure, are plotted against the stress in Figure 6. The rate of elongation can be seen to be a direct function of the applied stress.

In summary, the elongation of the polyester based magnetic tape starts with a negative value and increases directly with temperature, time at temperature, and with stress in the range of values tested.

When the data from the reheat behavior tests as called out in Table IV are compared to the plots in Figures 2a and 2c, it can be seen that the changes in length, both on the first thermal treatment and on the second thermal treatment, are consistent with data that was obtained previously, except that the points are more widely scattered. Unfortunately, there was a change in test technician which occurred at this time in the test program and there was no more time to recheck these points.

Figures 7 and 8 show the plots of Figures 2a and 2c, without the Phase 1 data points, and with the data points of Phase 4 added for comparison.

TABLE V.

Test Data

Test No.	Temperature degrees F	Stress psi	Heatup rate F/hr.	Time at Temp. hours	Percent While Hot	Change in Length After cooling	While cooling
1	150	100	80	1-1/4	.019	-.058	-.077
2	150	500	80	1-1/4	.135	.077	-.058
3	150	1,000	80	1-1/4	.212	.154	-.058
4	200	100	80	1-1/4	.058	-.115	-.173
4a					.077	-.038	-.115
5	200	500	80	1-1/4	.405	.288	-.117
6	200	1,000	80	1-1/4	.825	.655	-.170
7	250	100	80	1-1/4	.115	-.365	-.250
7a					.019	-.231	-.250
8	250	500	80	1-1/4	.830	.538	-.292
8a					.615	.346	-.269
9	250	1,000	80	1-1/4	2.13	2.04	-.27
10	300	100	80	1-1/4	.135	-.500	-.365
11	300	500	80	1-1/4	1.08	.712	-.296
12	300	1,000	80	1-1/4	3.31	2.98	-.33
13	250	100	80	3	.212	-.520	-.308
14	250	500	80	3	1.13	.807	-.32
15	250	1,000	80	3	2.94	2.63	-.31
16	250	100	80	6	.327	-.615	-.288
17	250	500	80	6	1.19	.865	-.32
18	250	1,000	80	6	3.77	3.48	-.29
19	250	100	50	1-1/4	.154	-.348	-.194
20	250	500	50	1-1/4	.808	.577	-.231
21	250	1,000	50	1-1/4	2.12	1.85	-.27
22	250	100	30	1-1/4	.096	-.270	-.174
22a					.115	-.635	-.520
23	250	500	30	1-1/4	.769	.519	-.250
24	250	1,000	30	1-1/4	2.08	1.85	-.23
24a					2.17	1.92	-.25

TABLE V. (continued)

Test No.	Temperature degrees F.	Stress psi	Heatup rate F/hr.	Time at Temp hours	Percent While Hot	Change in length After cooling	While cooling
25	250	100	Preheat	3	-.308	-.596	-.188
25a					-.231	-.520	-.289
26	250	500	Preheat	3	.615	.327	-.288
27	250	1,000	Preheat	3	2.02	1.79	-.23
28	250	100	80	1-1/4	-.190	-.462	-.272
29	250	100	80	1-1/4	-.154	-.481	-.327
30	250	100	80	1-1/4	-.135	-.404	-.269
31	250	100	80	1-1/4	-.135	-.423	-.288
32	250	100	80	6	-.250	-.461	-.211
33	250	100	80	6	-.269	-.539	-.270
34	250	100	80	6	-.481	-.770	-.289
35	250	100	80	6	-.289	-.596	-.307
36.1	250	100	80	1-1/4	-.154	-.384	-.230
36.2	150	100	80	1-1/4	.058	-.038	-.096
37.1	250	1,000	80	1-1/4	2.07	1.79	-.28
37.2	250	100	80	1-1/4	-.192	-.327	-.135
38.1	250	100	80	1-1/4	-.135	-.365	-.230
38.2	150	1,000	80	1-1/4	.212	.115	-.097
39.1	250	100	80	1-1/4	-.250	-.558	-.308
39.2	200	100	80	1-1/4	.154	.019	-.135
40.1	250	1,000	80	1-1/4	3.65	1.50	.215
40.2	200	100	80	1-1/4	-.019	---	---
41.1	250	100	80	1-1/4	.212	-.327	-.539
41.2	200	1,000	80	1-1/4	2.13	---	---
42.1	250	100	80	1-1/4	.367	-.147	-.514
42.2	250	100	80	1-1/4	-.037	---	---
43.1	250	1,000	80	1-1/4	2.93	1.69	-1.30
43.2	250	100	80	1-1/4	-1.69	---	---
44.1	250	100	80	1-1/4	data not usable		
44.2	250	1,000	80	1-1/4			

TABLE V. (continued)

Test No.	Temperature degrees F.	Stress psi	Heatup rate F/Hr.	Time at temp. hours	Percent While Hot	Change in length After cooling	While cooling
45.1	300	100	80	1-1/4	- .038	-.248	-.210
45.2	250	100	80	1-1/4	.000	---	---
46.1	300	1,000	80	1-1/4	3.76	3.48	-.28
46.2	250	100	80	1-1/4	.340	---	---
47.1	300	100	80	1-1/4	.038	-.208	-.246
47.2	250	1,000	80	1-1/4	1.47	---	---

TABLE VI.

Test Data Variability

Test Conditions:

Temperature 250° F
 Stress 100 psi
 Heatup Rate 80° F/hour
 Time at Temp. 1.25 hour

	Mean	Standard Deviation	
	% Change in length	% Change in length	Fraction of mean
While Hot -	.118	.072	0.61
After Cooling -	.394	.090	0.23
While Cooling -	.279	.028	0.10

Test Conditions:

Temperature 250° F
 Stress 100 psi
 Heatup Rate 80° F/hour
 Time at Temp. 6 hours

	Mean	Standard Deviation	
	% Change in length	% Change in length	Fraction of Mean
While Hot -	.323	.093	0.29
After Cooling -	.596	.115	0.19
While Cooling -	.273	.037	0.14

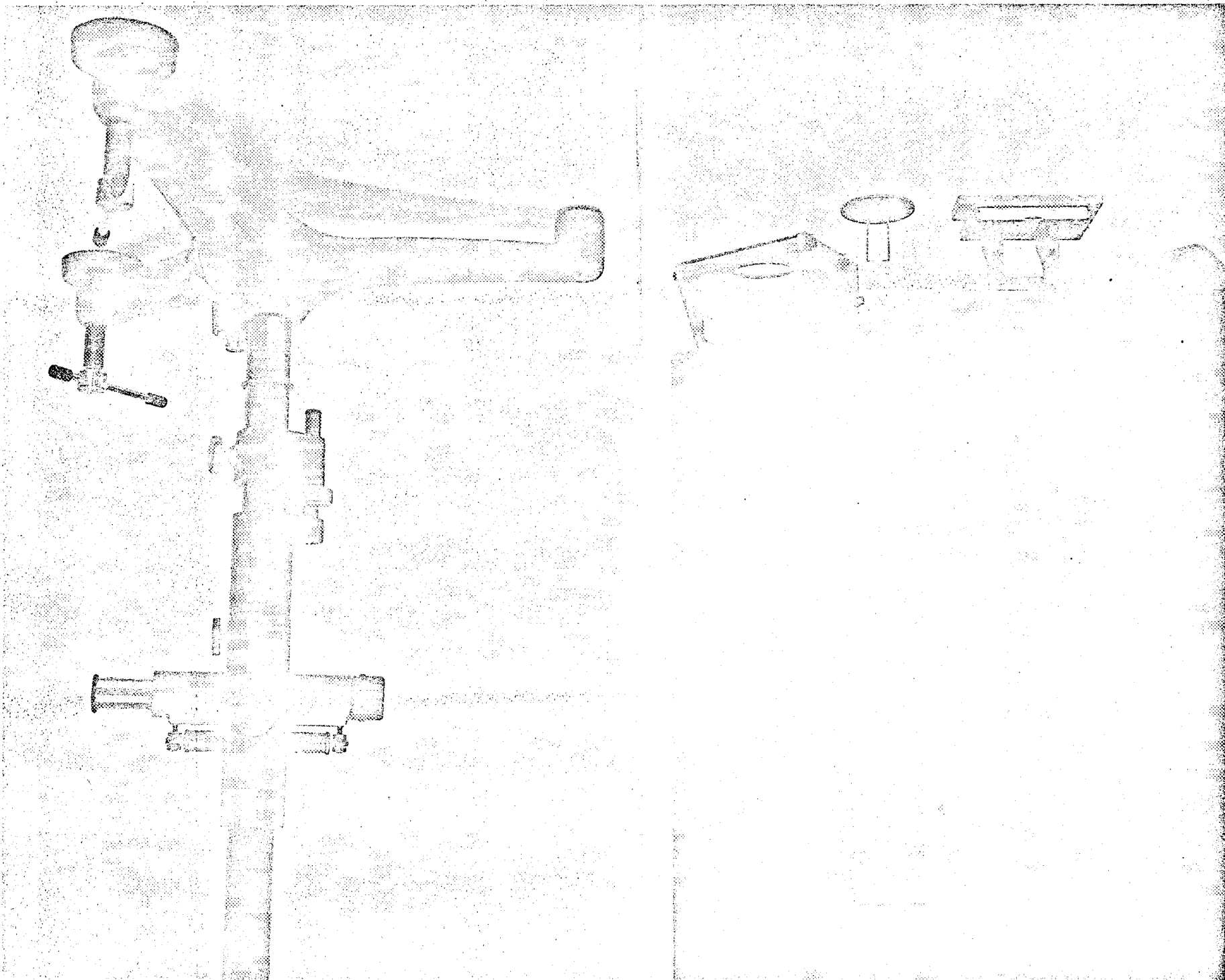


FIGURE 1

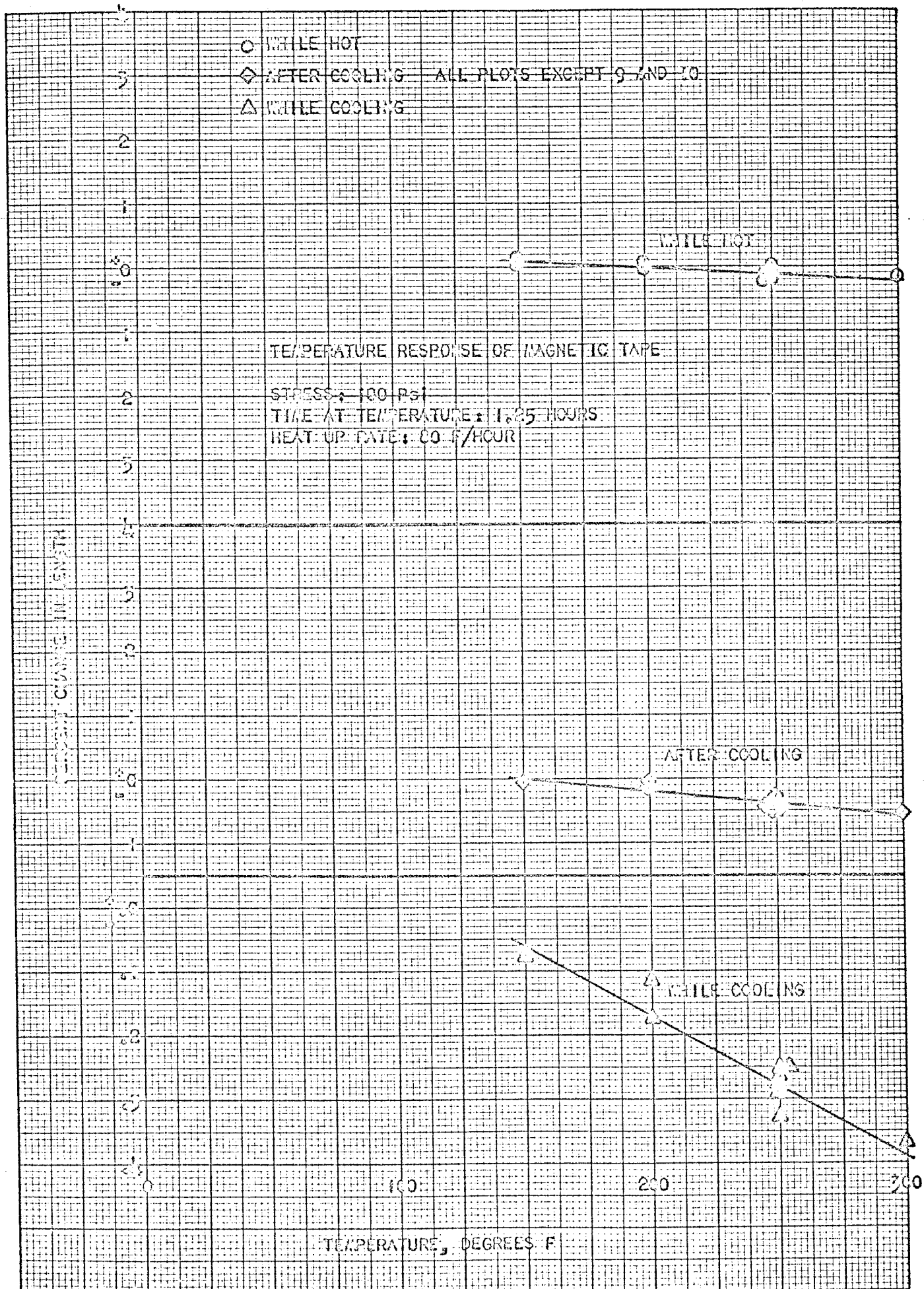


FIGURE 2 a

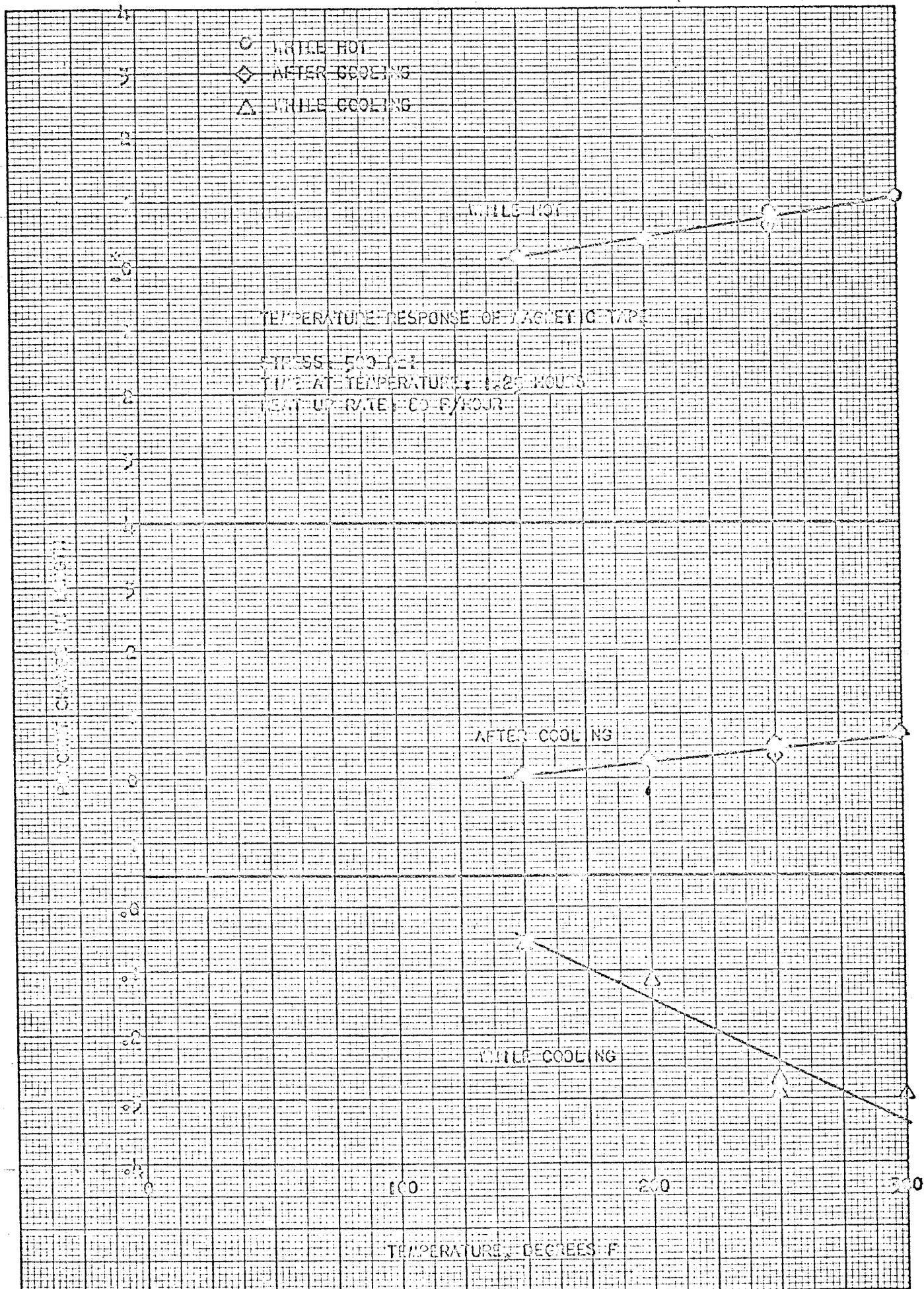


FIGURE 2 b

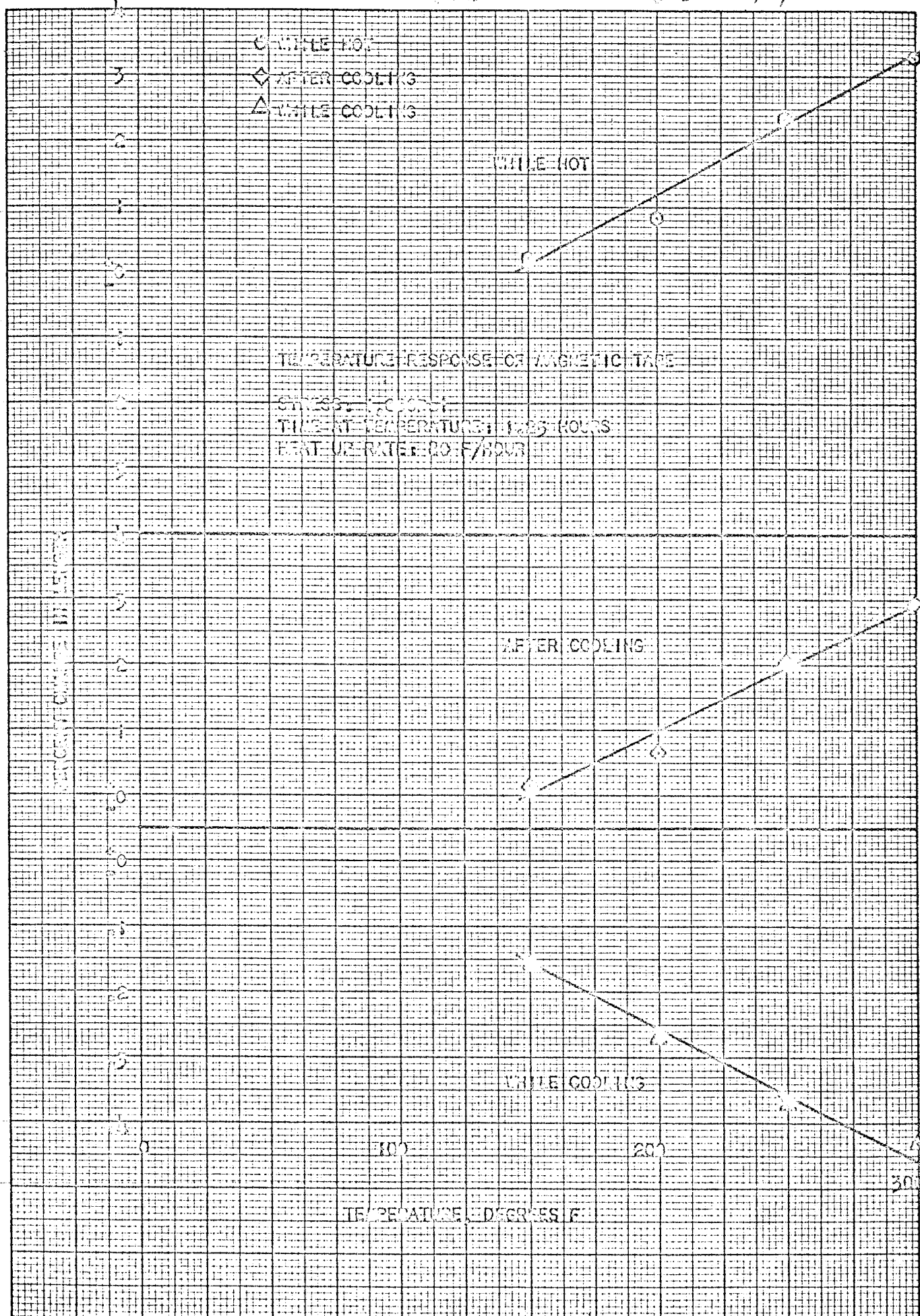
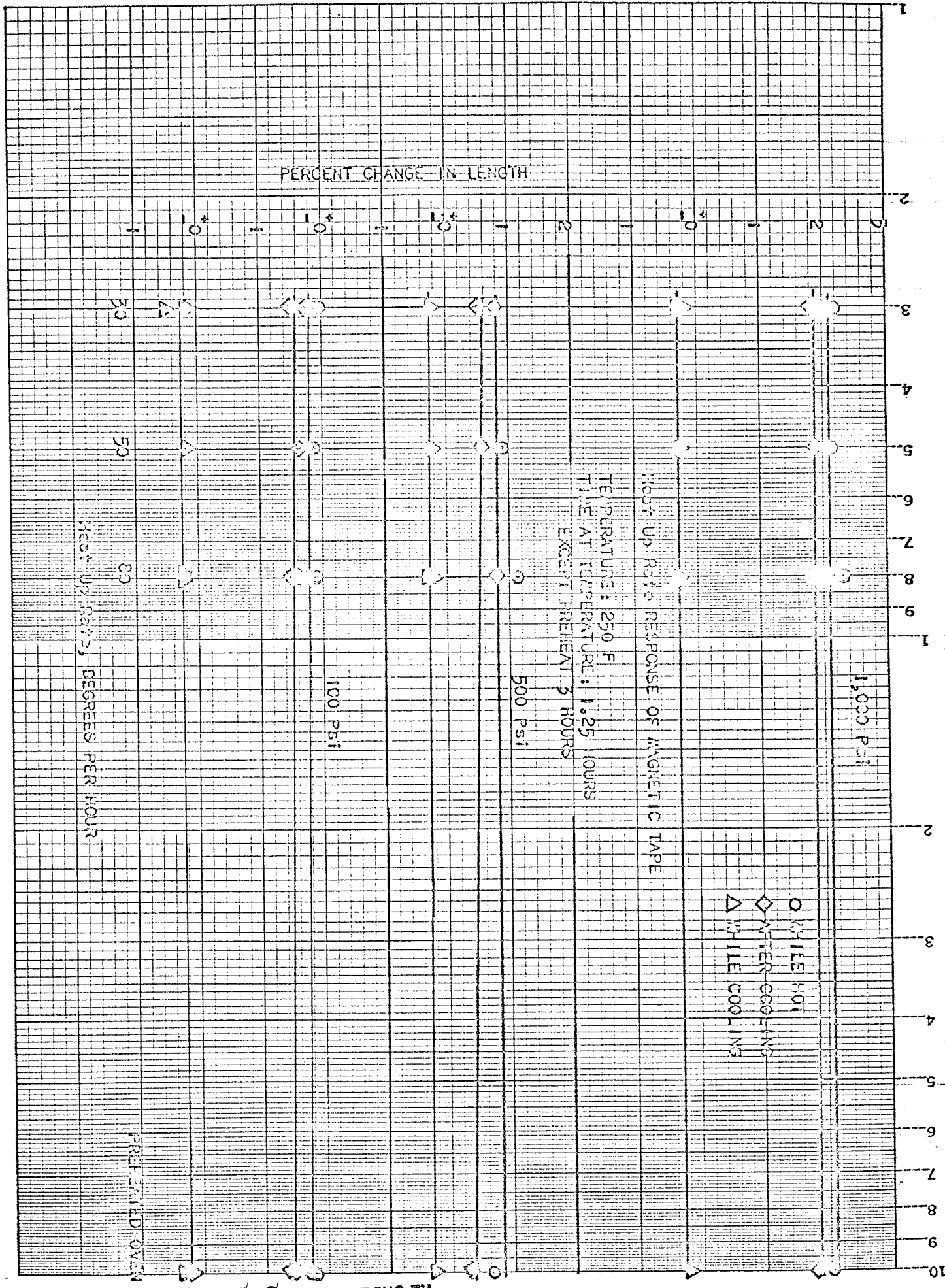


FIGURE 2 c

FIGURE 3



RE-ORDER NO. 66-94

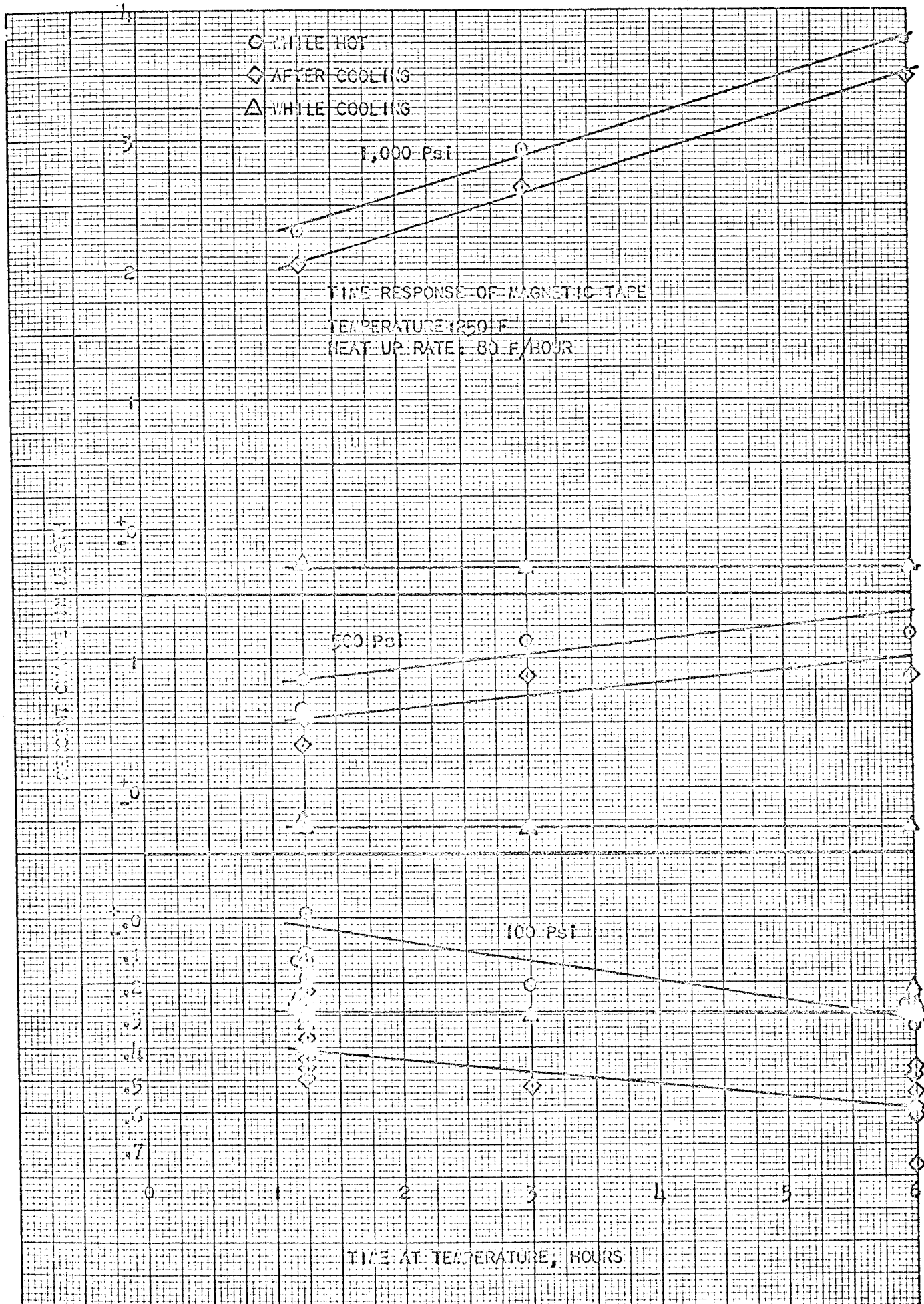


FIGURE 4

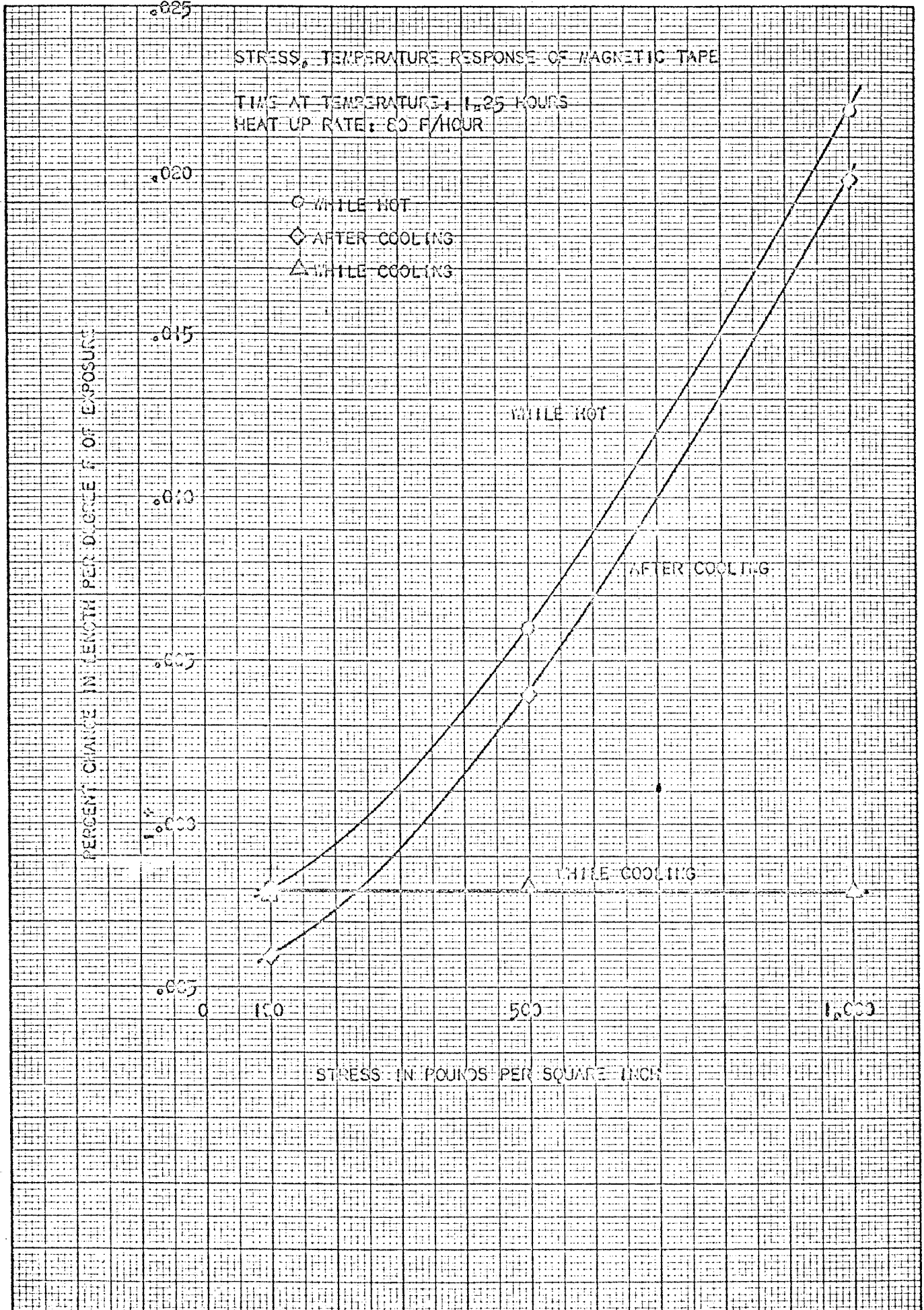


FIGURE 5

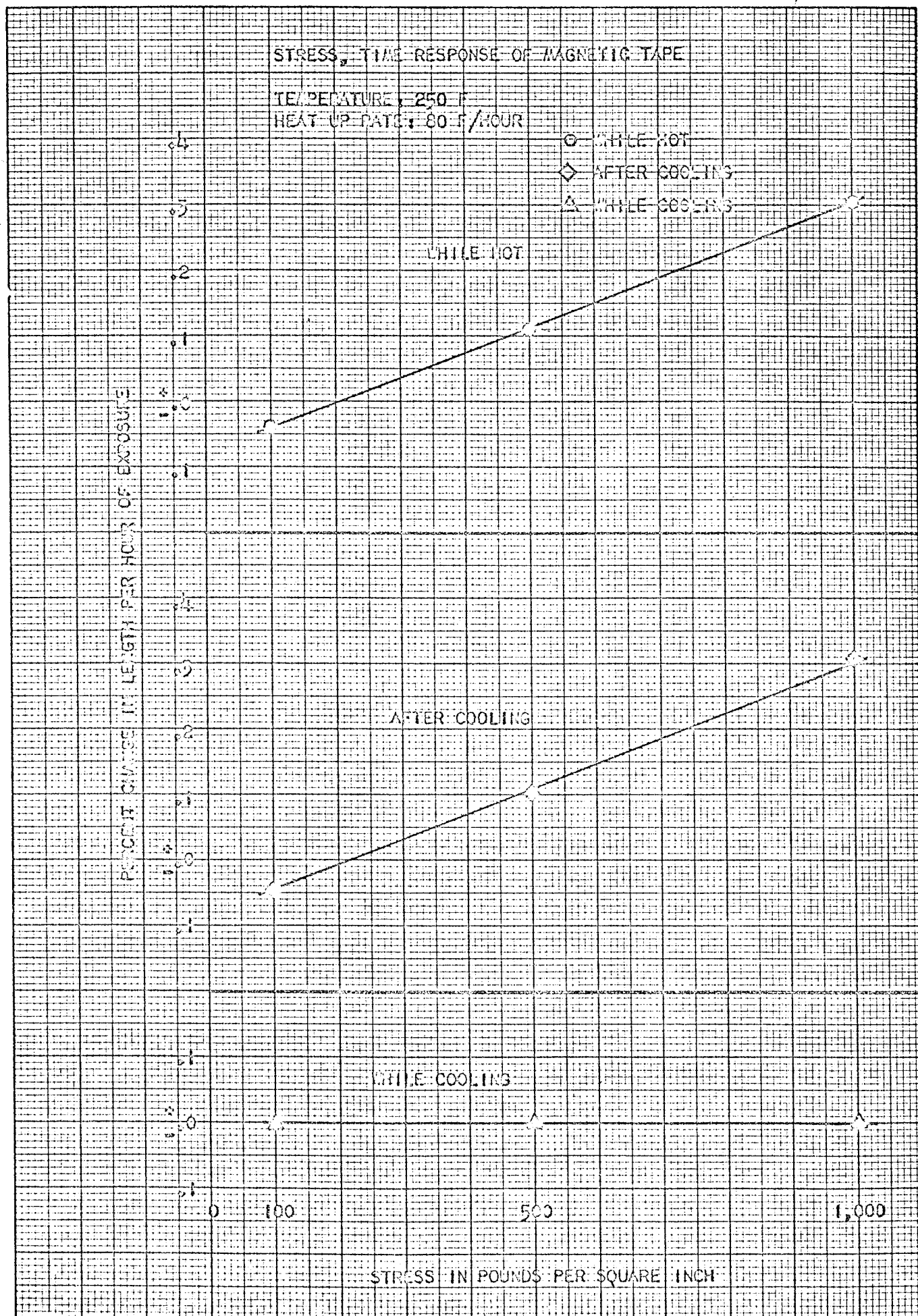


FIGURE 6

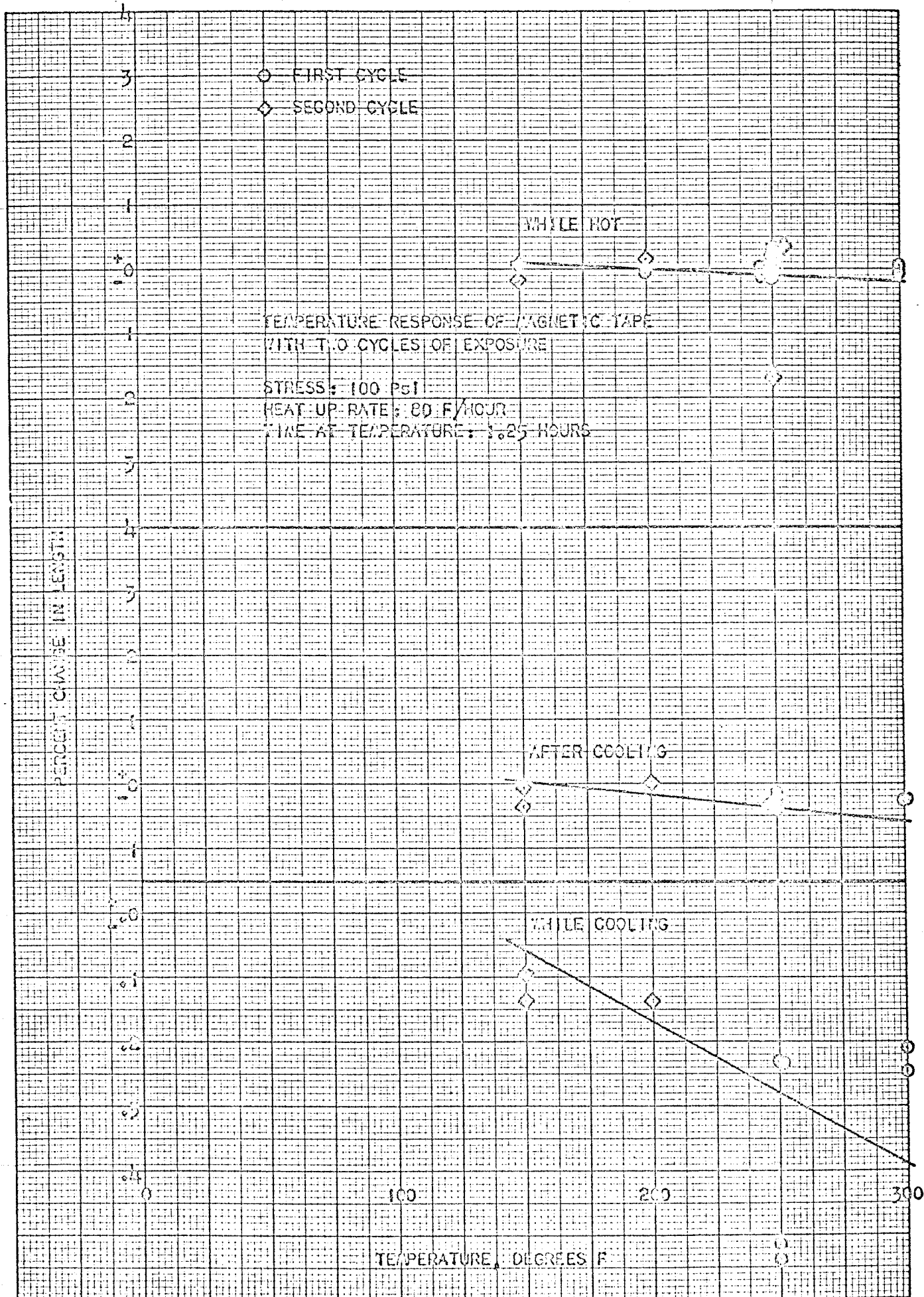


FIGURE 7

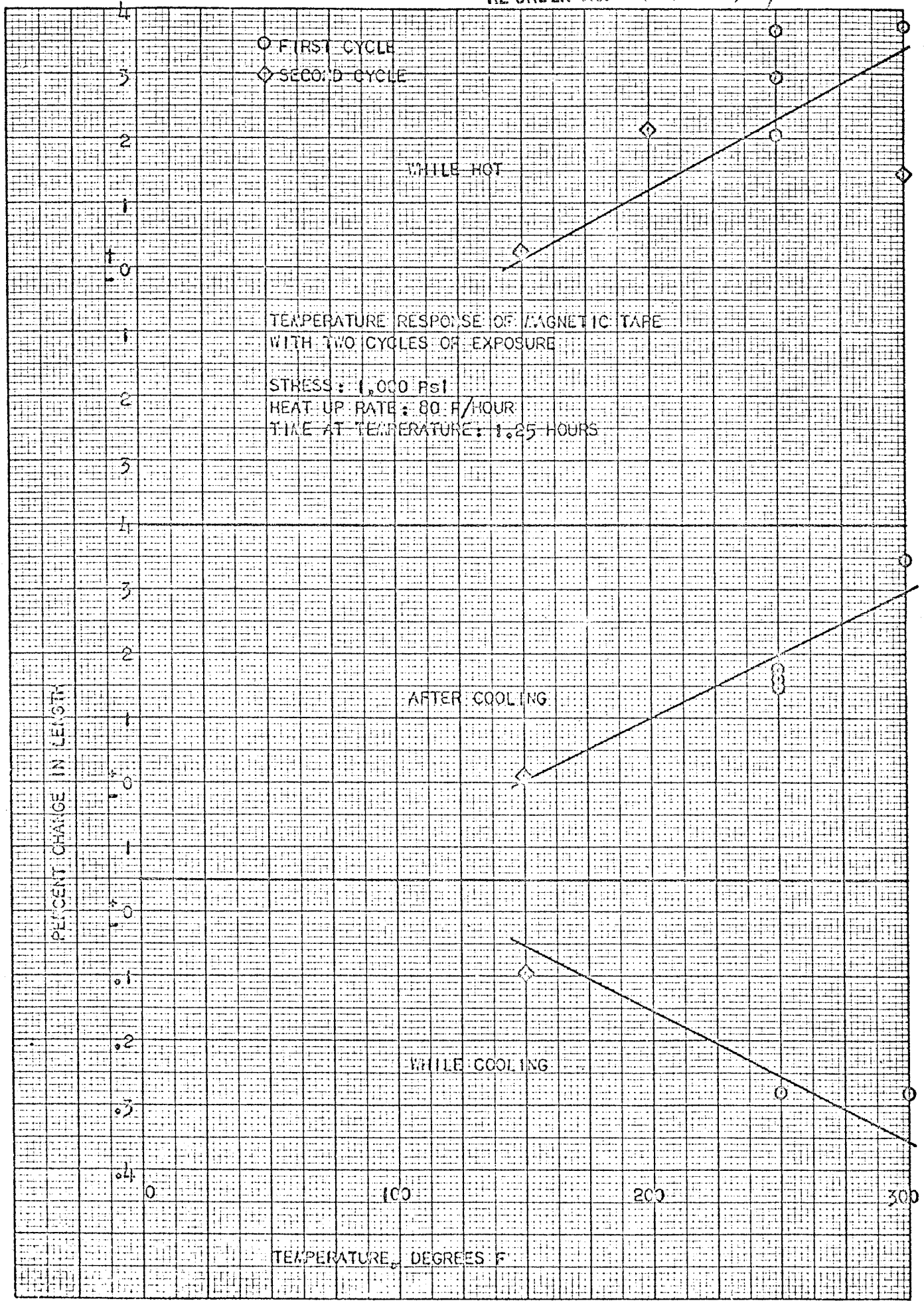


FIGURE 8